

# ***OCCULTATION SCIENCE AND APPLICATIONS IN EUROPE: THE CONTRIBUTION AND ROLE OF ESA***

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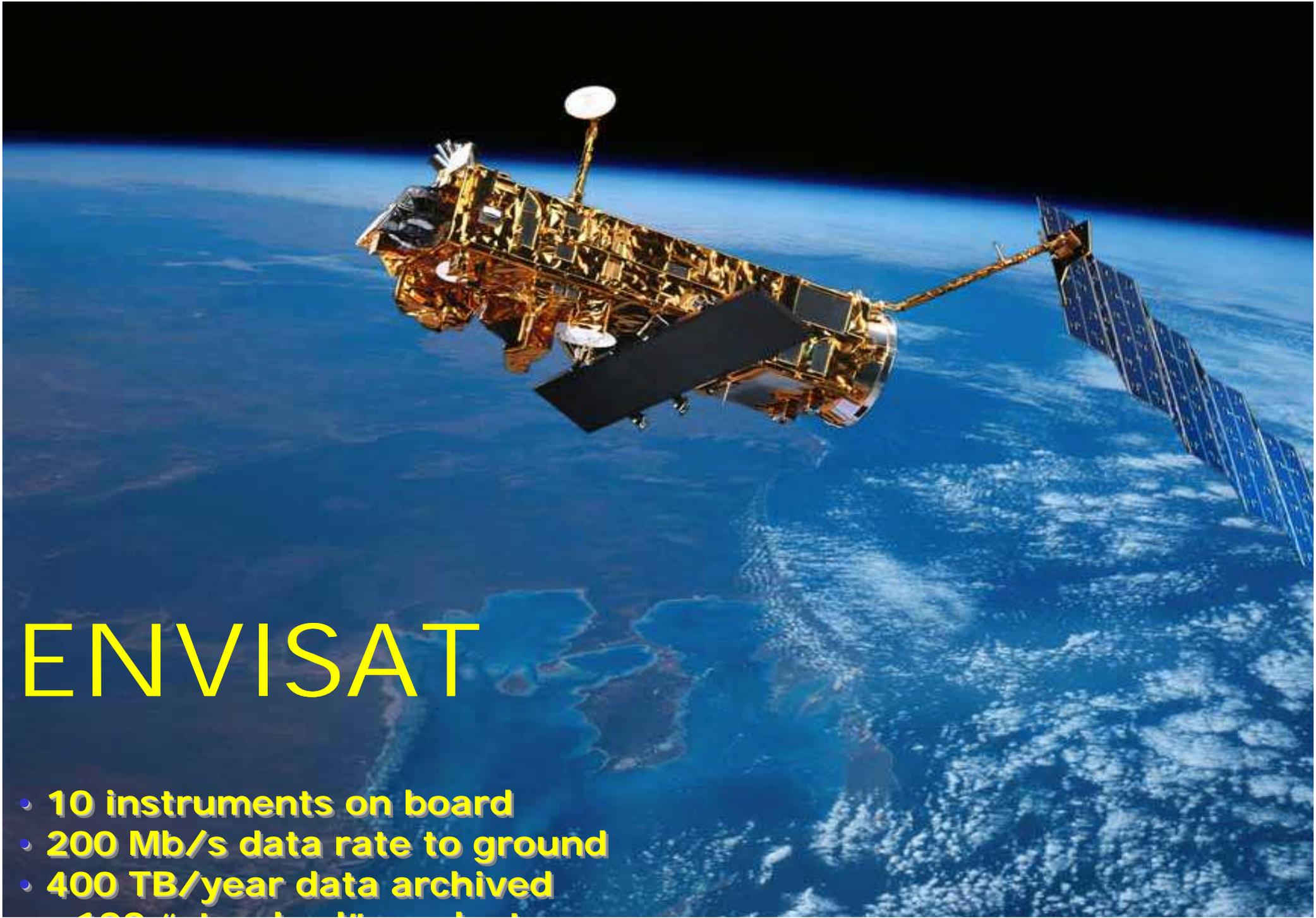
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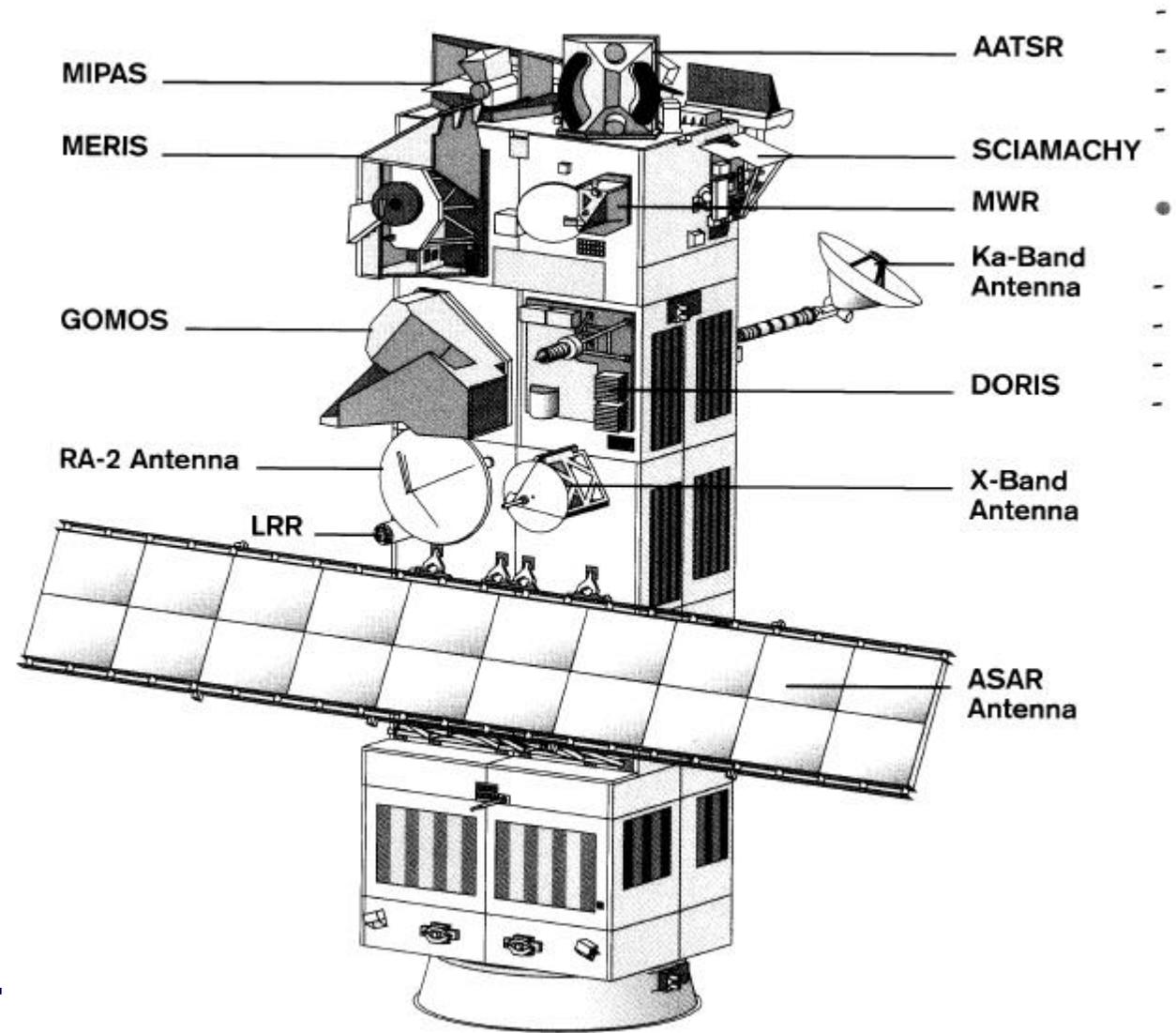
- Background
- A resume' of developments
- Outlook: ACE+
- Galileo and modernised GPS
- Conclusions

- Optical occultation missions and instruments on Envisat:
  - Global Ozone Monitoring by Occultation of Stars (GOMOS)
  - SCanning Imaging Absorption SpectroMeter for Atmospheric CHartography (SCIAMACHY) - AO instrument (NL-D cooperation)
  
- Radio occultation missions and instruments
  - GRAS(S)
  - APEW
  - APM, ACE, WATS & ACE+
  - GRAS-2 and LEO-LEO instruments



# ENVISAT

- 10 instruments on board
- 200 Mb/s data rate to ground
- 400 TB/year data archived



Medium-resolution grating spectrometer

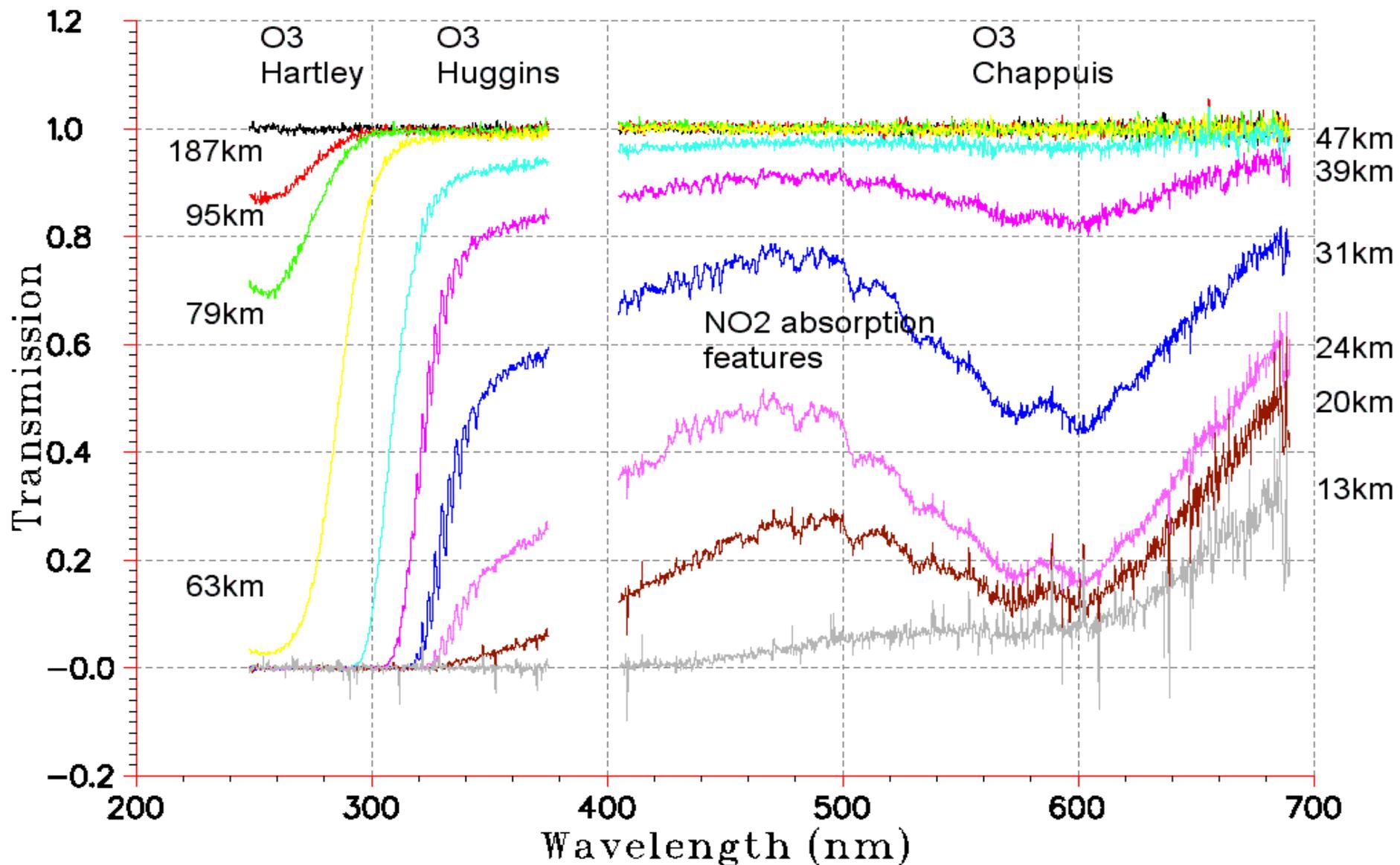
UV-visible	250-675 nm, 1.2 nm	O <sub>3</sub> , NO <sub>2</sub> , NO <sub>3</sub> , aerosol (extc.), (OCIO)
Near IR (1)	756-773 nm, 0.2 nm	O <sub>2</sub> (density and temperature)
Near IR (2)	926-952 nm, 0.2 nm	H <sub>2</sub> O
“Blue” & “red” photometer	470-520 nm & 650-700 nm	scintillations (high resolution T profile)

**Main Mission Objectives**

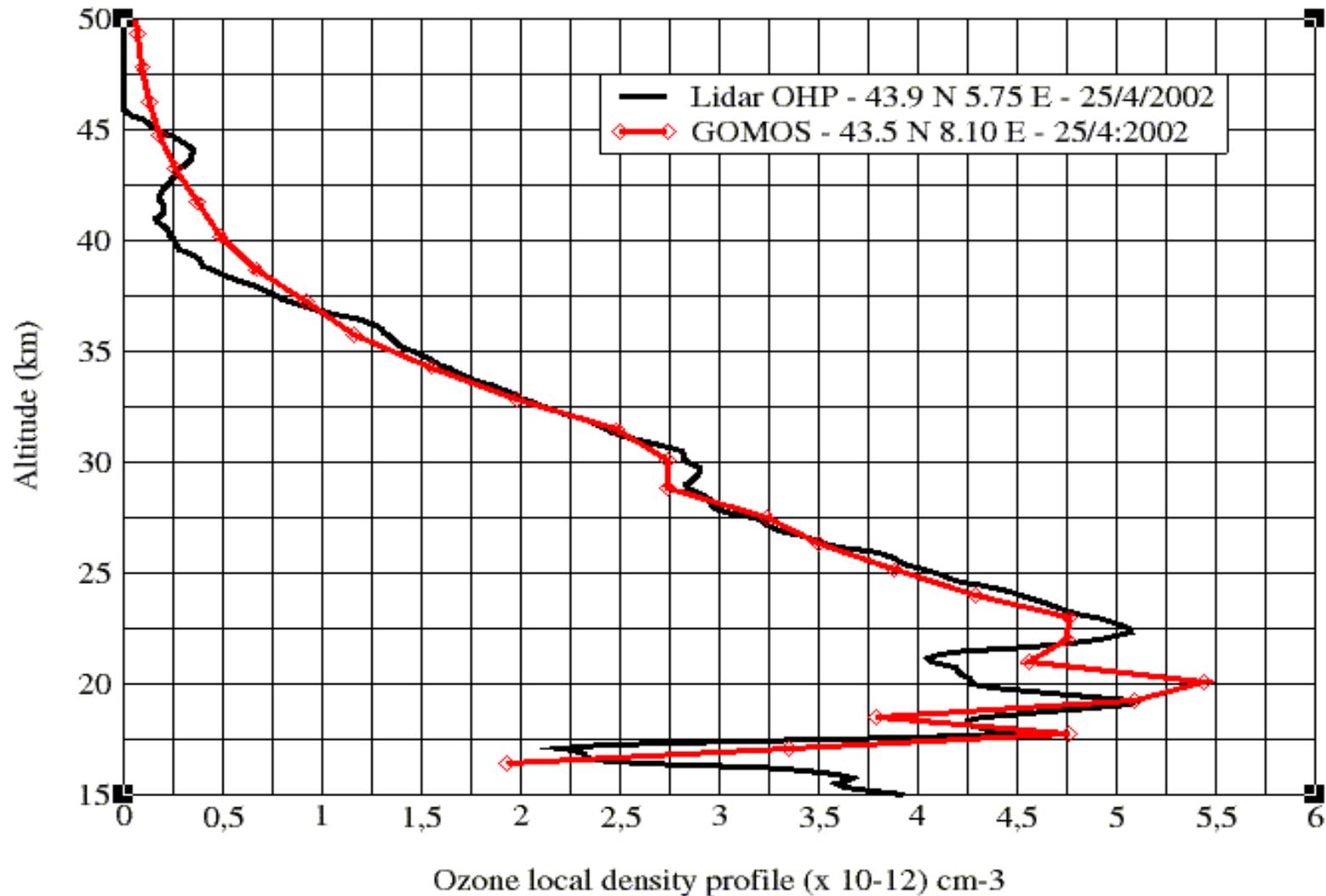
- Global ozone monitoring (profiles in mesosphere and mid/upper stratosphere)
- Calibration of other ozone sensors
- Stratospheric chemistry (profiles of ozone NO<sub>2</sub>, NO<sub>3</sub>, H<sub>2</sub>O, aerosol, OCIO, BrO)
- Stratospheric dynamics (high resolution temperature profile, ozone)
- Noctilucent clouds (around 85 km)
- Demonstration of stellar occultation as long-term monitoring (profiling) instrument for the stratosphere and mesosphere

**Data Products**

- atmospheric transmittance spectra (Level 1b data product)
- line-of-sight column densities and vertical profiles of O<sub>3</sub>, NO<sub>2</sub>, NO<sub>3</sub>, air density, aerosol extinction (3 spectral parameters), O<sub>2</sub> (density, temperature), H<sub>2</sub>O
- high-resolution temperature profile (from scintillation)

**Atmospheric transmittances in UV and VIS measured on 6 May with bright and hot star**


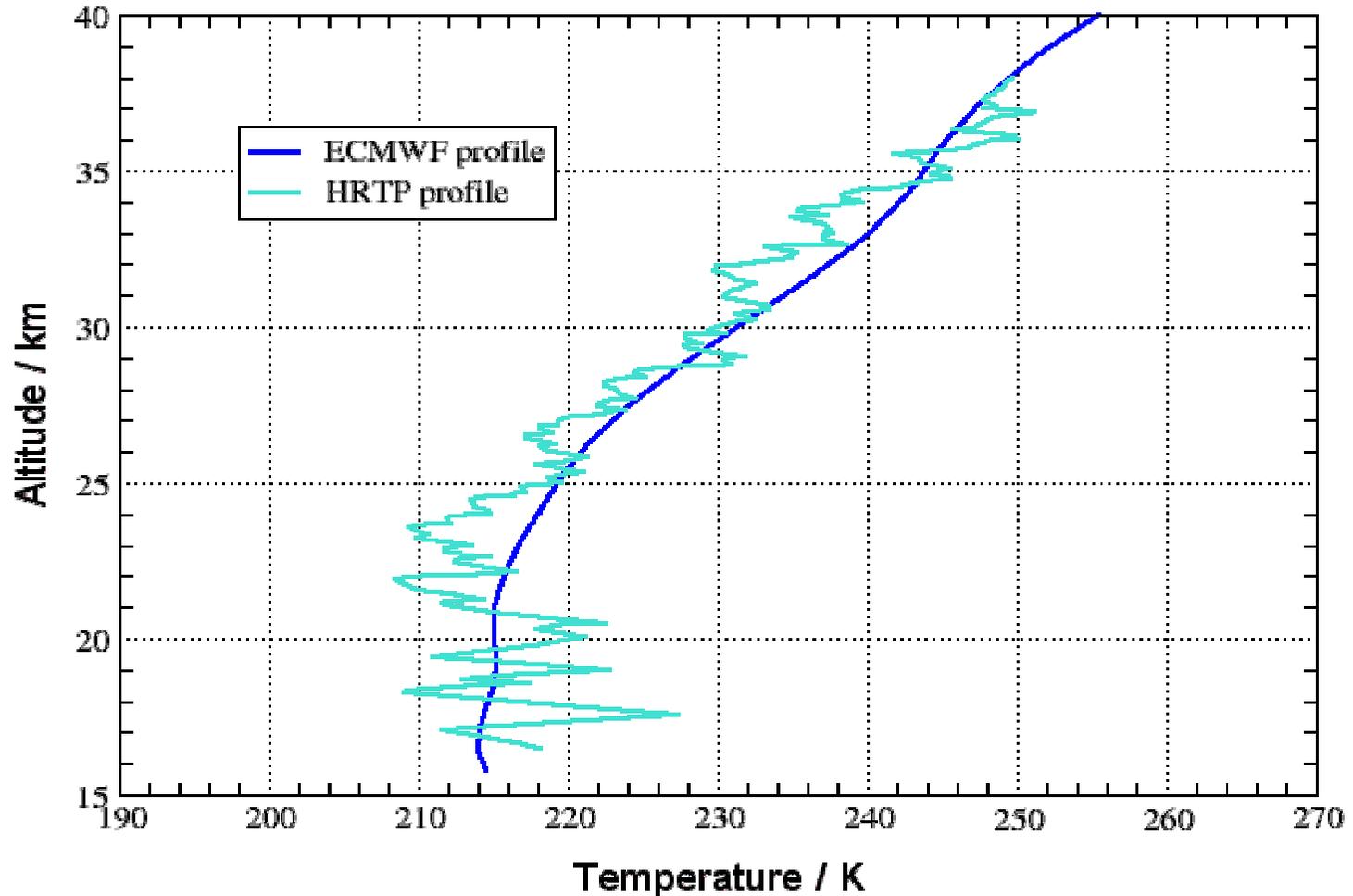
Comparison of retrieved ozone profile measured on 25 April 2002 with collocated lidar measurement at Observatoire Haute Provence (after A. Hauchecorne)



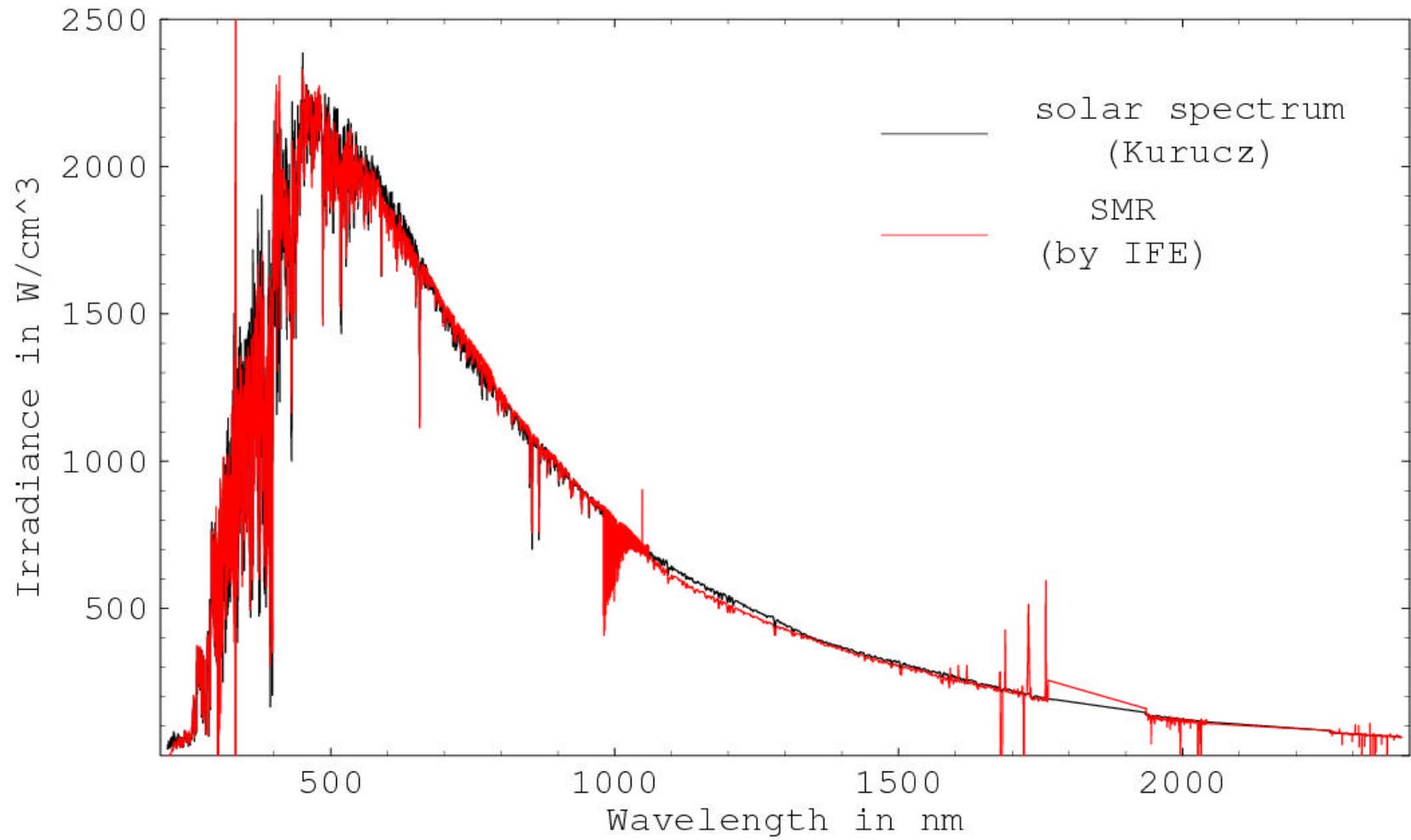
**GOMOS High Resolution Temperature Profile (H RTP)  
in comparison with ECMWF analysis profile**

*High-resolution temperature retrieval from fast photometer (green curve, 25 April 2002) compared to collocated ECMWF analysis (blue curve).*

*(after A. Hauchecorne)*



- **SCIAMACHY = Scanning Imaging Absorption SpectroMeter for Atmospheric Cartography**
- **goal: global measurements of trace gases in the troposphere and stratosphere**
- **measures sunlight transmitted, reflected and scattered by the earth in the UV, VIS and NIR (240 nm - 2380 nm) at moderate spectral resolution (0.2 nm - 1.5 nm)**
- **observes same volume of air under different viewing geometries (occultation, nadir, limb)**
- **new IR channels w.r.t. GOME**
- **differential optical absorption applied in sun and moon elevation (sun occultation once per orbit in N. hemisphere, moon occultation every second orbit in S. hemisphere when possible)**
- **first results: overall in good shape; validation results by December**

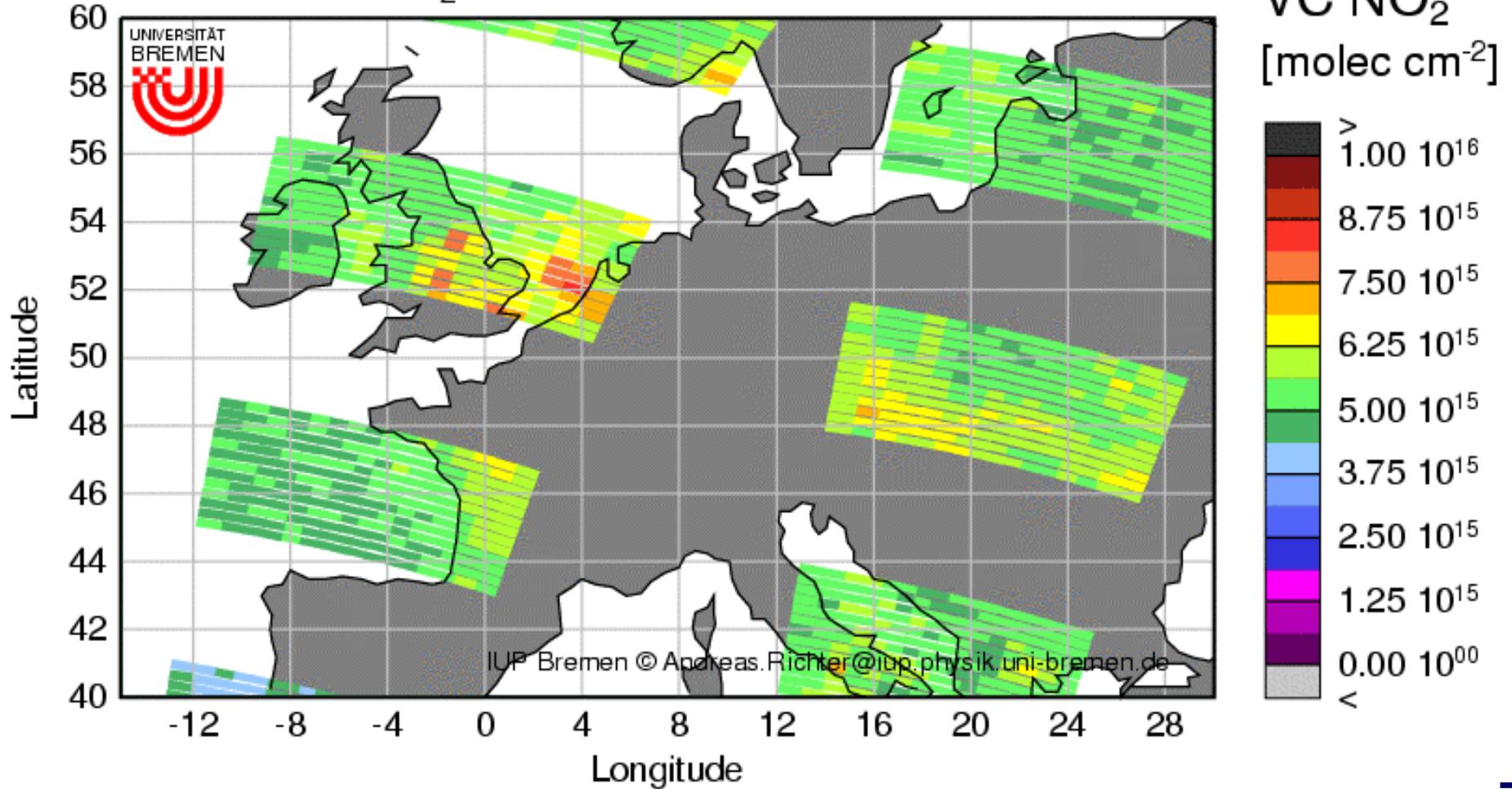


OPAC-1

19 September 2002



SCIAMACHY NO<sub>2</sub> columns based on lv1 data: 2002/08/10

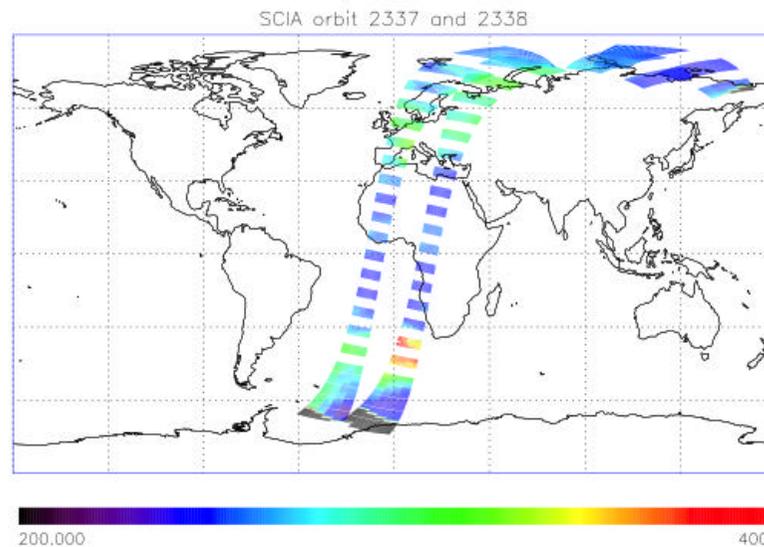
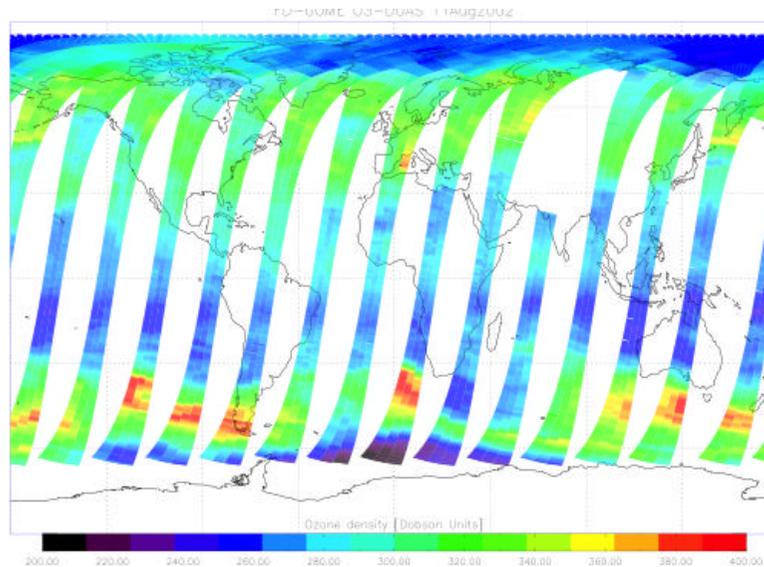


# TOTAL OZONE

GOME (ERS-2)



SCIAMACHY



- No planetary heritage (at ESA mission level)
  
- 1989: first "introduction" to RO:
  - Aristoteles (now GOCE)
  - NASA/JPL TurboRogue-type receiver
  - secondary experiment (GGI -derived concept)
  
- 1992: EXTRAS (experiment on timing, ranging and atmospheric sounding):
  - experiment of opportunity with GPS receiver, H-maser, PRARE,.. on Russian platform
  - first involvement of DMI and CNRS/Service Aeronomie
  - first contacts with Russian radio occultation community (MI R-GEO experiments, GPS RO concepts)
  - first look at RO implementation
  - lack of European space receiver of 'geodetic quality'

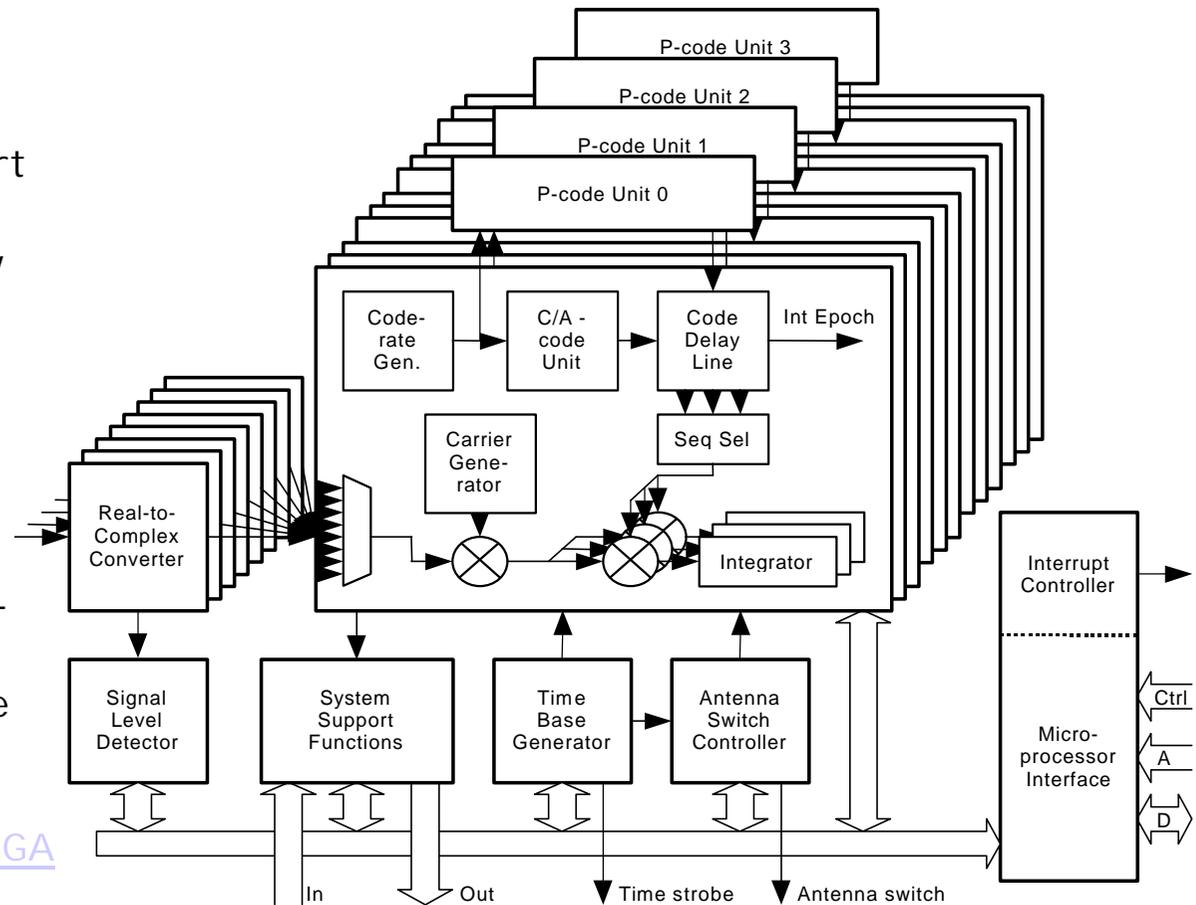
- 1993/5: study of derivation of atmospheric properties using RO
  - DMI , CNRS, Univ. Graz
  - interesting results on ionospheric effects and gravity wave detectability
  - first simulator tools developed
  - team building!
  
- 1993/5: pre-development of GPS/GLONASS receiver:
  - Oriented to geodetic applications
  - breadboards built at Univ. Leeds
  - first analysis of instrument RO implementation requirements
  - GRASS, GRAS or ....?

- 1994/5: antenna development:
  - SAAB Ericsson Space (S) selected
  - ambitious requirements
  - suspended skin technology
  - not so easy...
  
- 1995/7: integration of digital processing circuitry:
  - first attempt based on Leeds breadboards
  - Advanced GPS/GLONASS ASIC (AGGA) chip with 4 dual-frequency channels, adaptive codeless tracking, high flexibility,...
  - AGGA-0: commercial technology, several bugs, but...
  
- 1995/6: first results from GPS-MET
  - very encouraging results for retrievals
  - simulations of received signals reasonably faithful
  - successful proof-of-concept

=> goal: develop fully space-qualified/operational instrument

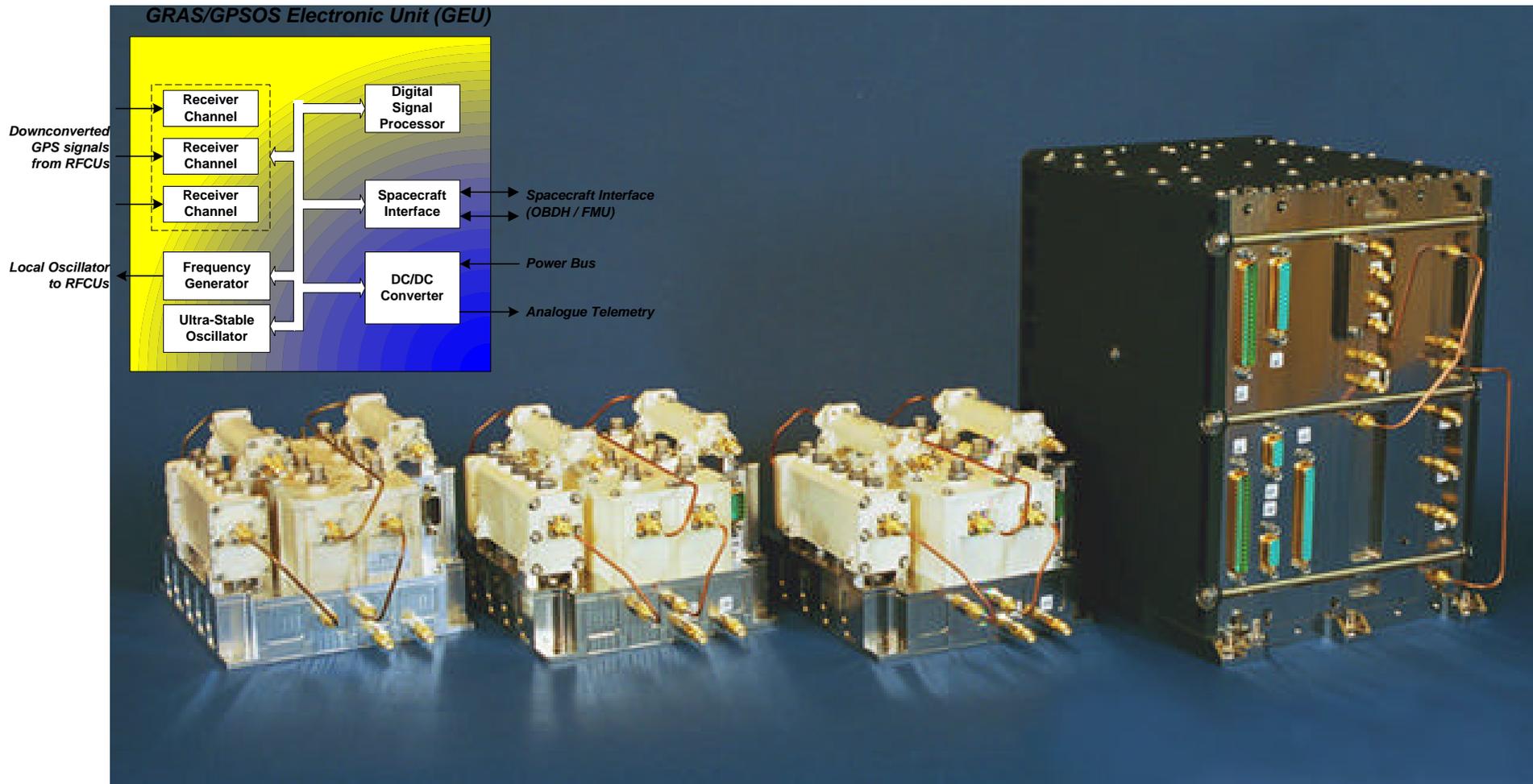
- 1995/6: requests to Eumetsat and ESA for a GRASS instrument on MetOp:
  - results from GPS/MET used to back proposal
  - yellow light.. then green!
  - joint ESA-Eumetsat Scientific Advisory Group
  - but...:
    - no working AGGA chip yet
    - accommodation on multi-instrument satellite far from trivial: radio interferences (10 W from S&R transmitter...); antenna field-of-views;..); interfaces with satellite with mature design;...
  
- 1996/8: pre-development of GRAS with MetOp as target carrier:
  - contract to SAAB Ericsson Space & Austrian Aerospace
  - intense design activity, later continued with development of hardware-representative breadboard
  
- 1997: award of GPSOS (GPS Occultation Sensor) "Phase A" contract to European consortium by US NPOESS - design very much based on GRAS, will fly in 2009 with ionospheric measurements as primary objective

- 1996: problems with AGGA chip development:
  - design work taken over by ESA/ESTEC (unusual!):
    - functional specifications and support to architectural design from EOPP
    - detailed (re-)design of chip logic by Micro-electronics Section
  - decision for an Application-Specific Standard Product, openly available
  - interactions with future users (not only with winners of GRAS development contract)
  - finally successful development of AGGA-2a!
  - since 1998, orders for >200 chips at the silicon foundry (ATMEL)
  - see Data Sheet on web, e.g. at <ftp://ftp.estec.esa.nl/pub/eopp/pub/AGGA/datasheet.pdf>



- 1996-2001: End-to-end GNSS Occultation Performance Simulator (EGOPS):
  - Comprehensive and powerful simulation tool for research, mission analysis, processing of actual data,...
  - Currently available to the scientific and industrial communities via ESA or via Univ. Graz
  - First version with Terma (DK), Univ. Graz, DMI
  - Work on follow-on versions (currently release 4) led by Univ. Graz
  - Very valuable contributions by M Gorbunov on wave optics propagation and 'diffraction correction'
  - Functions recently added:
    - » high-resolution radiosonde-based atmospheric model;
    - » high sampling rate and highly realistic receiver model;
    - » enhanced diffraction correction;
    - » simulation of airborne RO events;
    - » ionospheric profiling;
    - » optimal estimation

- 1996-2001: series of scientific studies on:
  - Error analyses
  - Retrieval and data assimilation methods and problems (e.g., ionospheric correction; horizontal variability; Fresnel transform-based diffraction correction; statistical optimisation;..)
  - Atmospheric imaging, tropopause mapping, climate monitoring
  - Tracking through lower troposphere and water vapour retrieval
  - OSSE for NWP and climate change studies
  - Near-real-time POD
  - Teams involved: Univ. Graz, DMI , MPI , UKMO, KNMI , I EEC, ACRI ,..
  
- Many results presented at two Seminars on RO at ESTEC in Jan. 1998 and Jan. 2000
- Large additional development work for implementing GRAS on MetOp to operational standards
- Rigorous performance characterisation and optimisation (carrier tracking expected down to ~1 km)



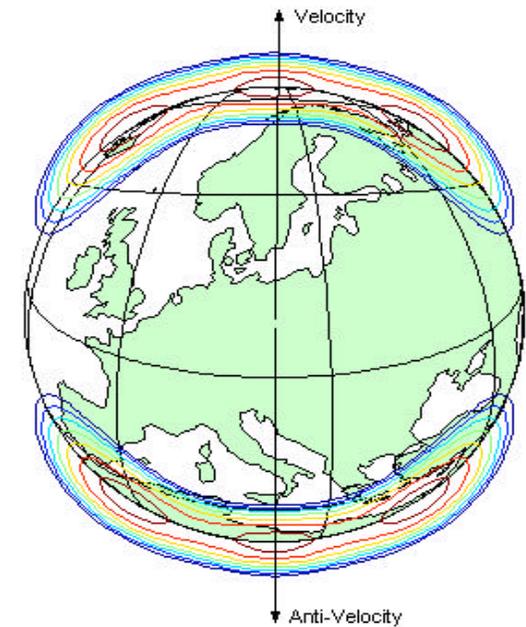
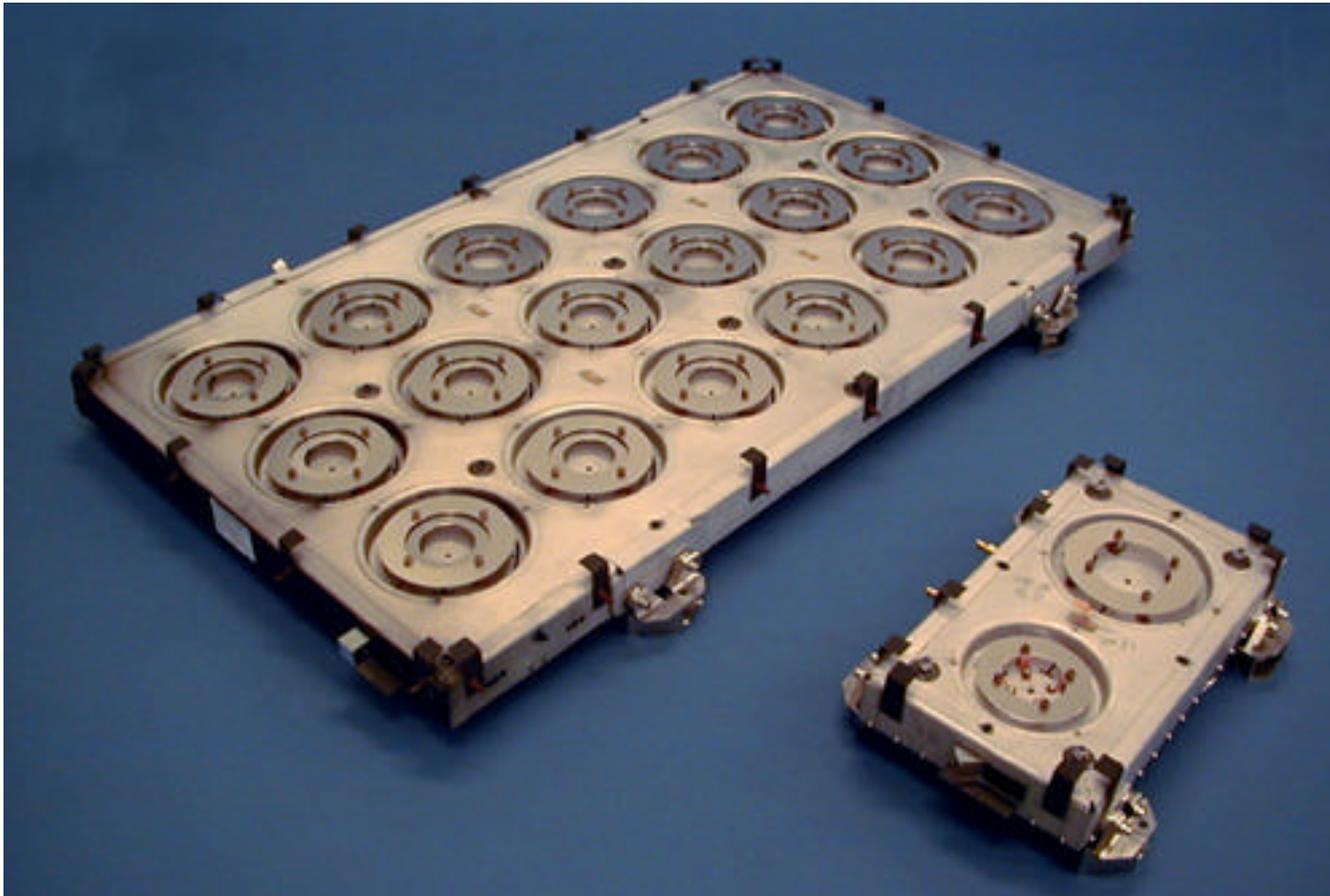
Ref.: Silvestrin et al., *Spaceborne GNSS Radio Occultation Instrumentation for Operational Applications*, Proc. of the International ION GPS Meeting, ION-GPS 2000, Salt Lake City (USA), Sept. 2000



esa

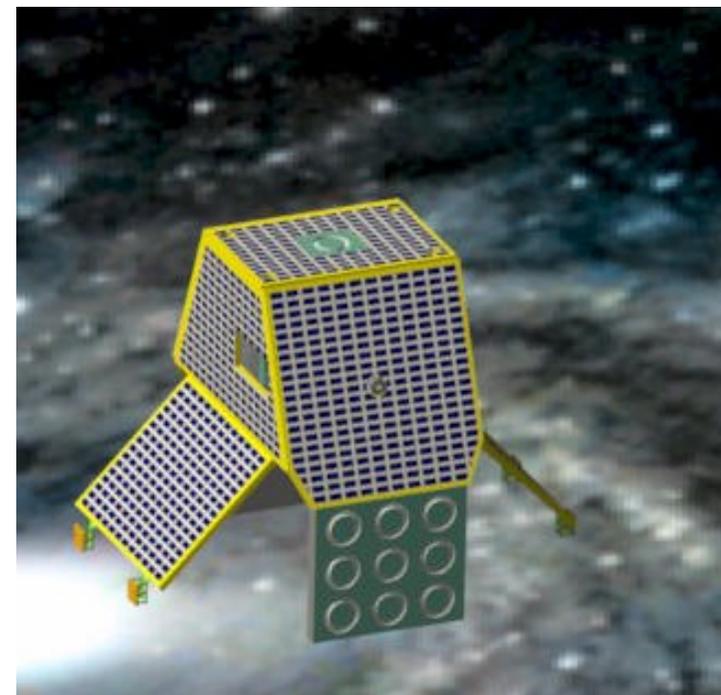
## GRAS for MetOp: Antennae

EO Future  
Programmes

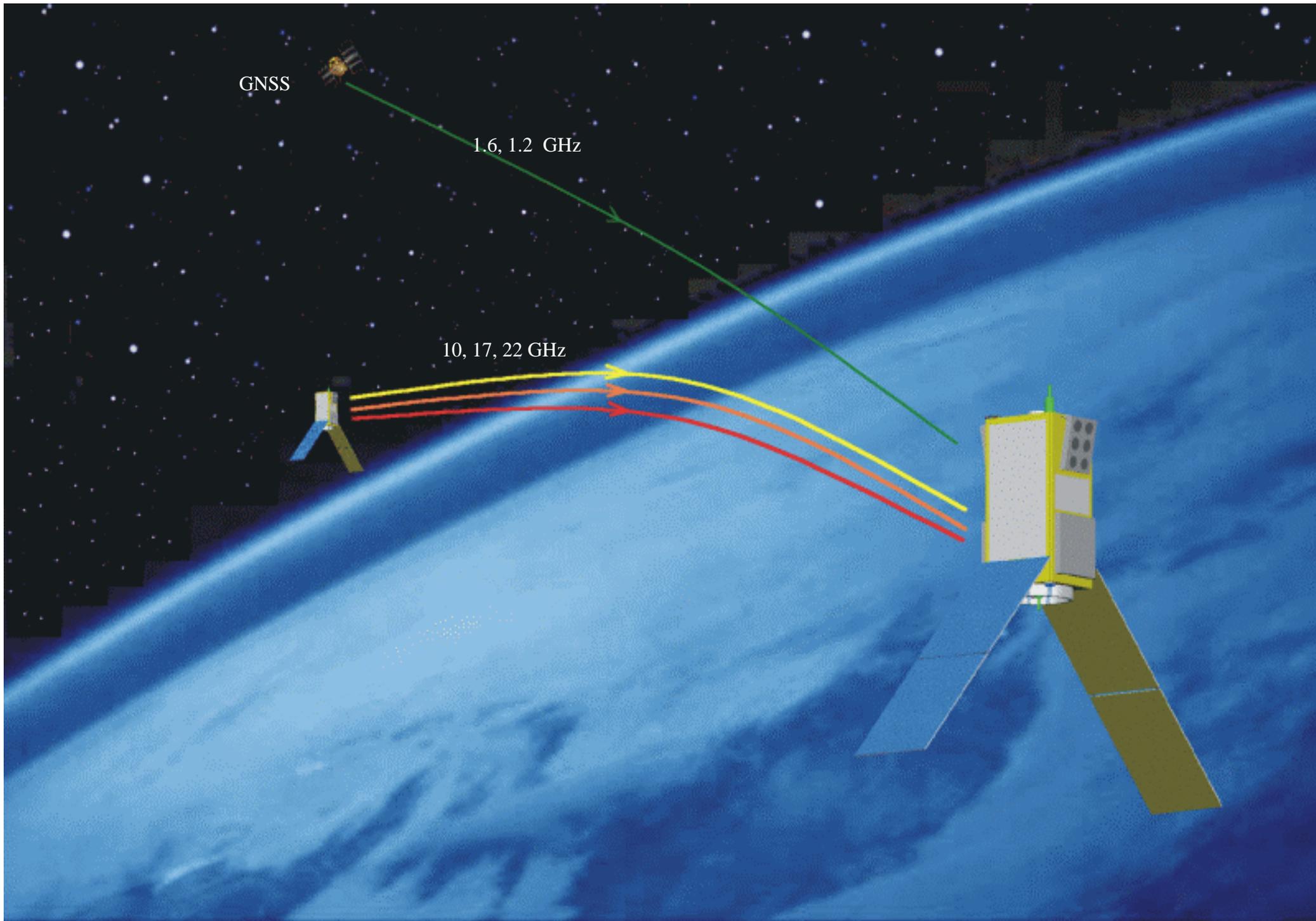


Ref. Hassel, *Dual Frequency Patch Antenna for GPS Occultation Measurements*, 25th ESA Antenna Workshop on Satellite Antenna Technology, ESTEC, Sept. 2002

- EW:
  - Call for Proposals in 1997
  - System definition studies performed
- Earth Explorers:
  - Atmospheric Profiling Mission
  - Atmospheric Climate Experiment (ACE)
  - Water vapour and Temperature in Troposphere and Stratosphere (WATS)
  - Atmosphere and Climate Explorer + (ACE+)



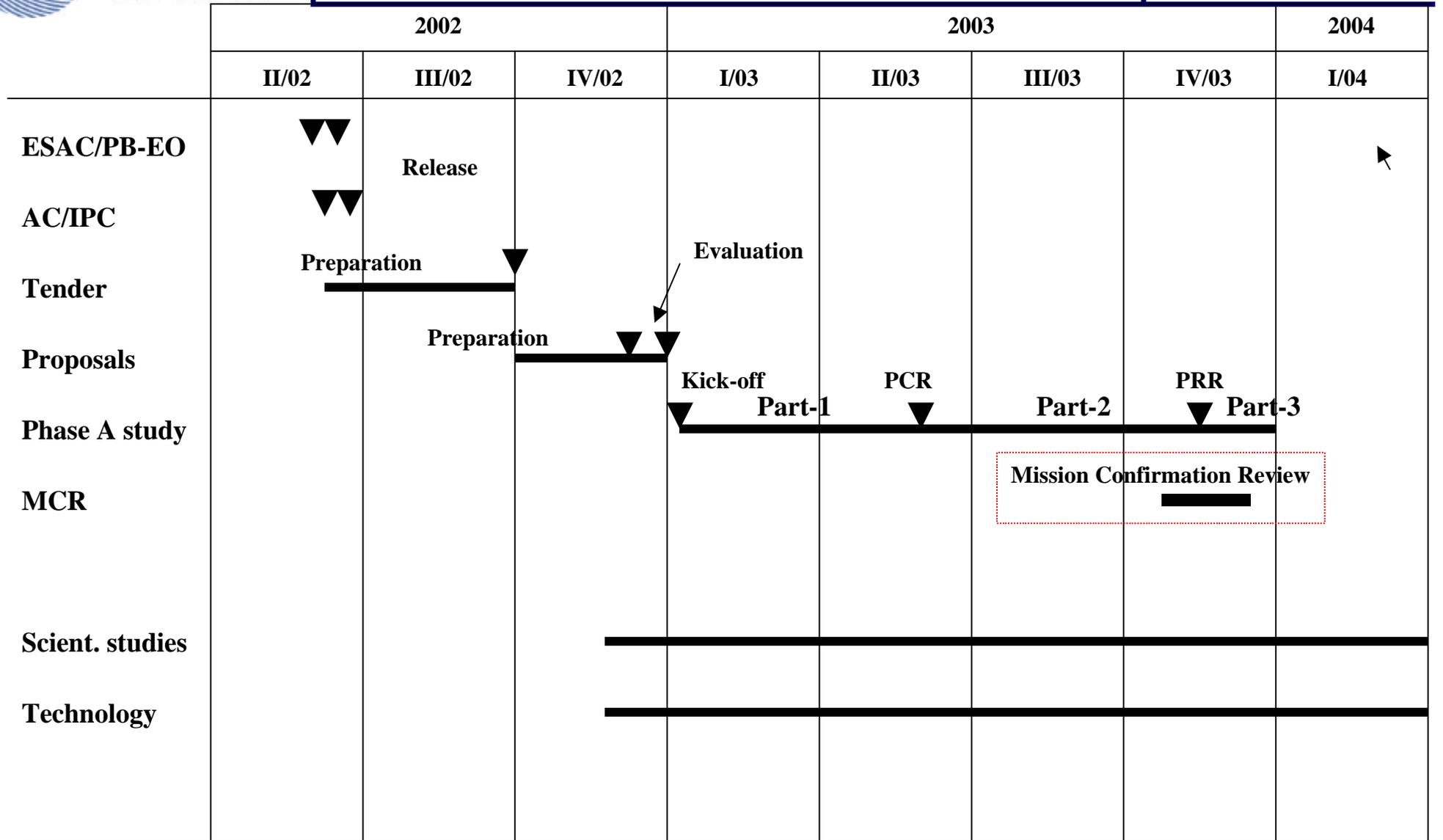
ACE satellite  
configuration  
with GRAS-2





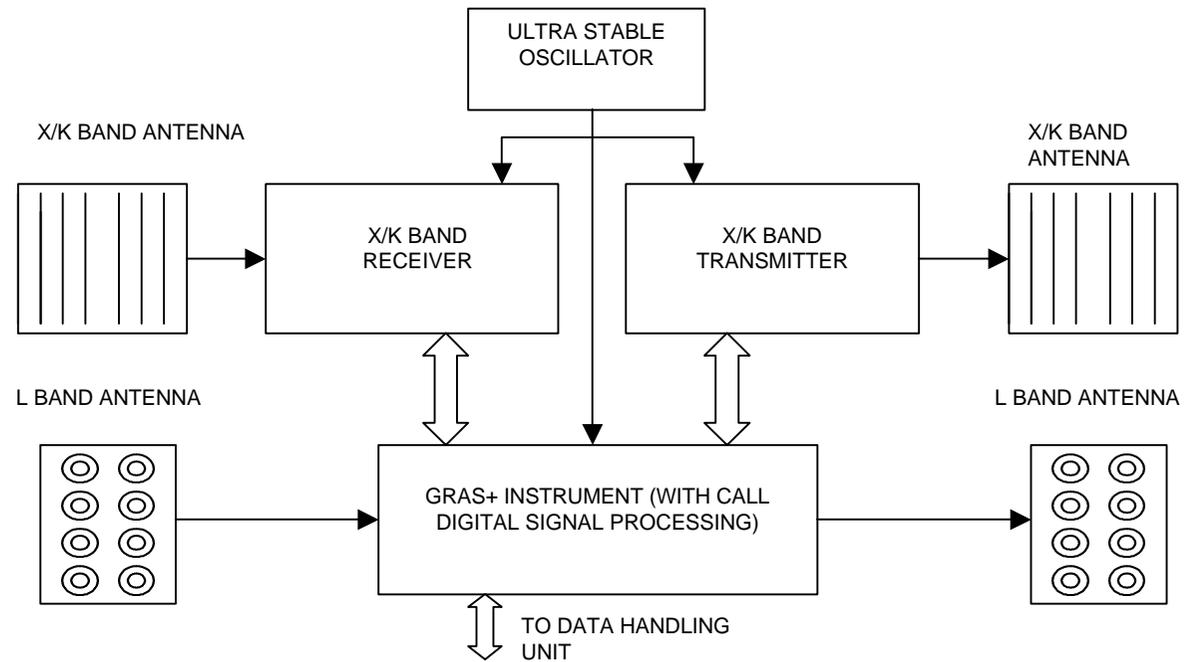
# Selected EEOM: the Next Step

EO Future Programmes



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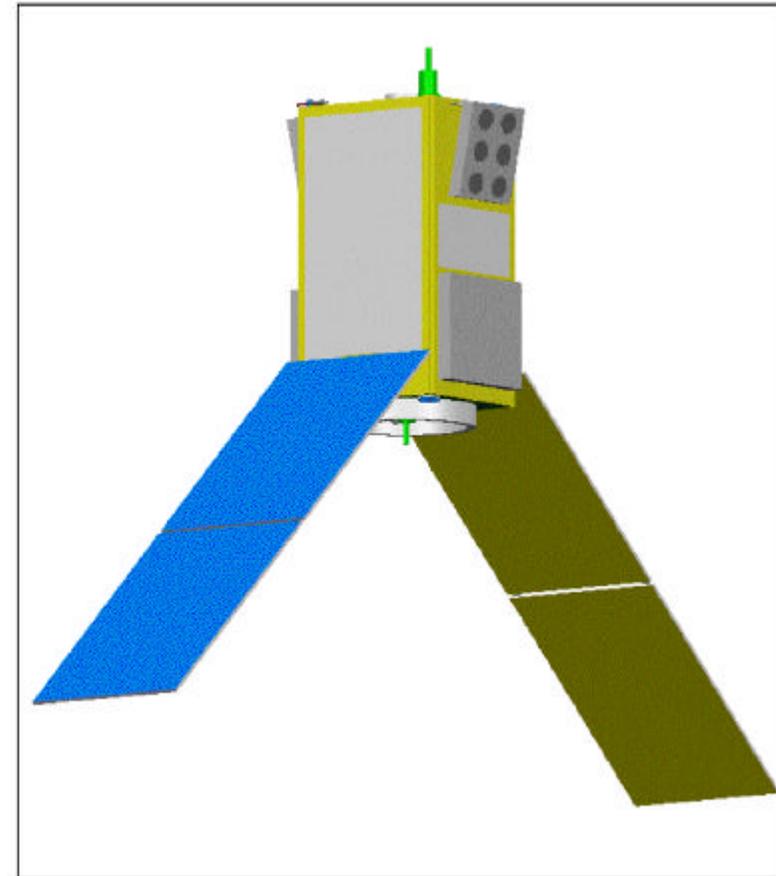
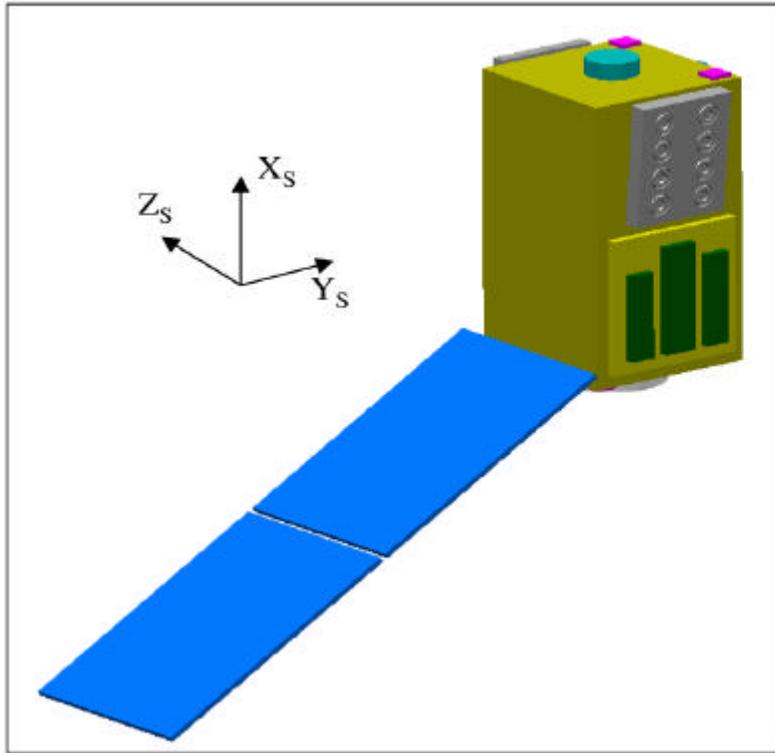




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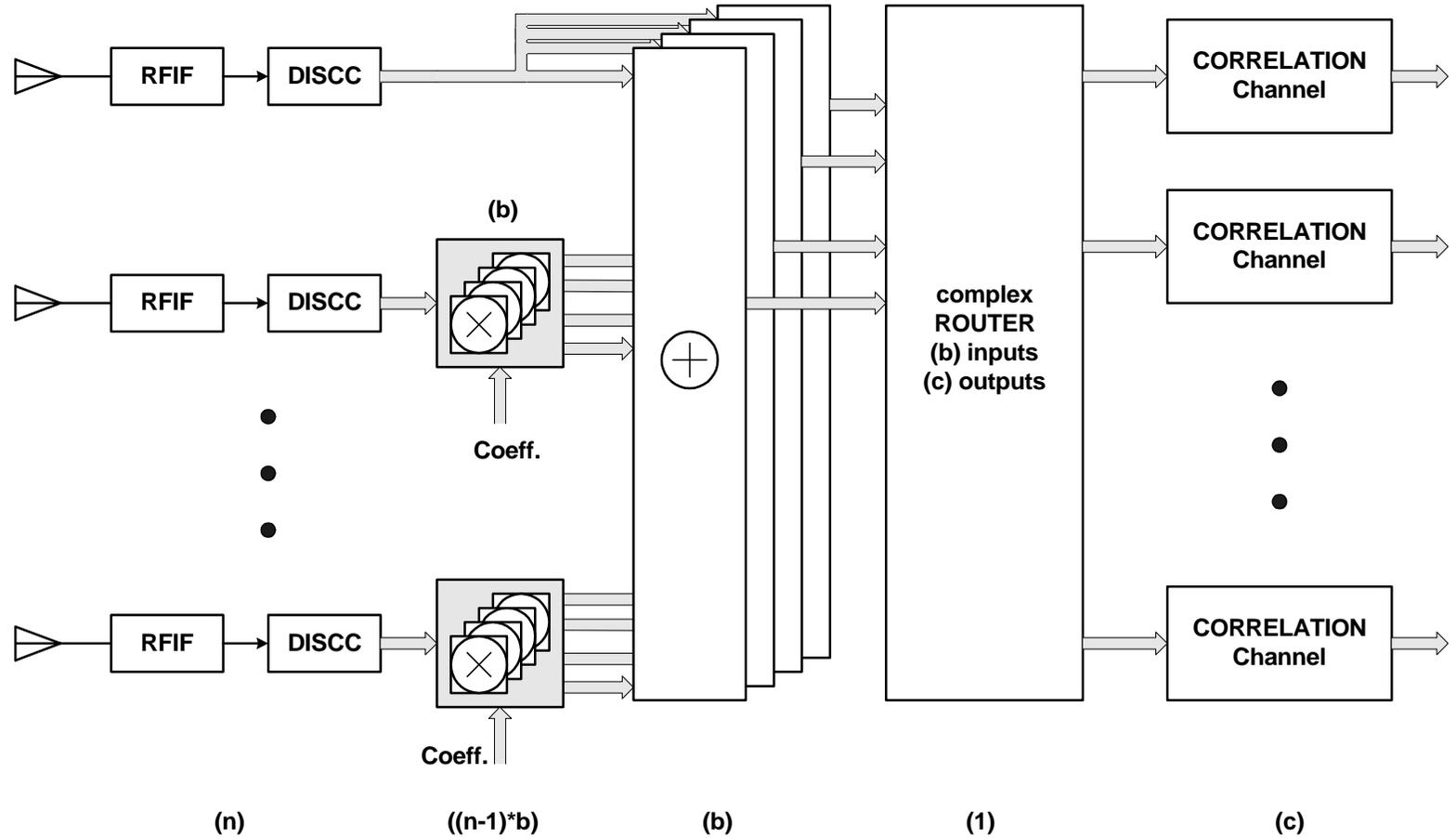
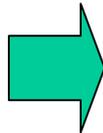
*WATS Concept: Satellite*

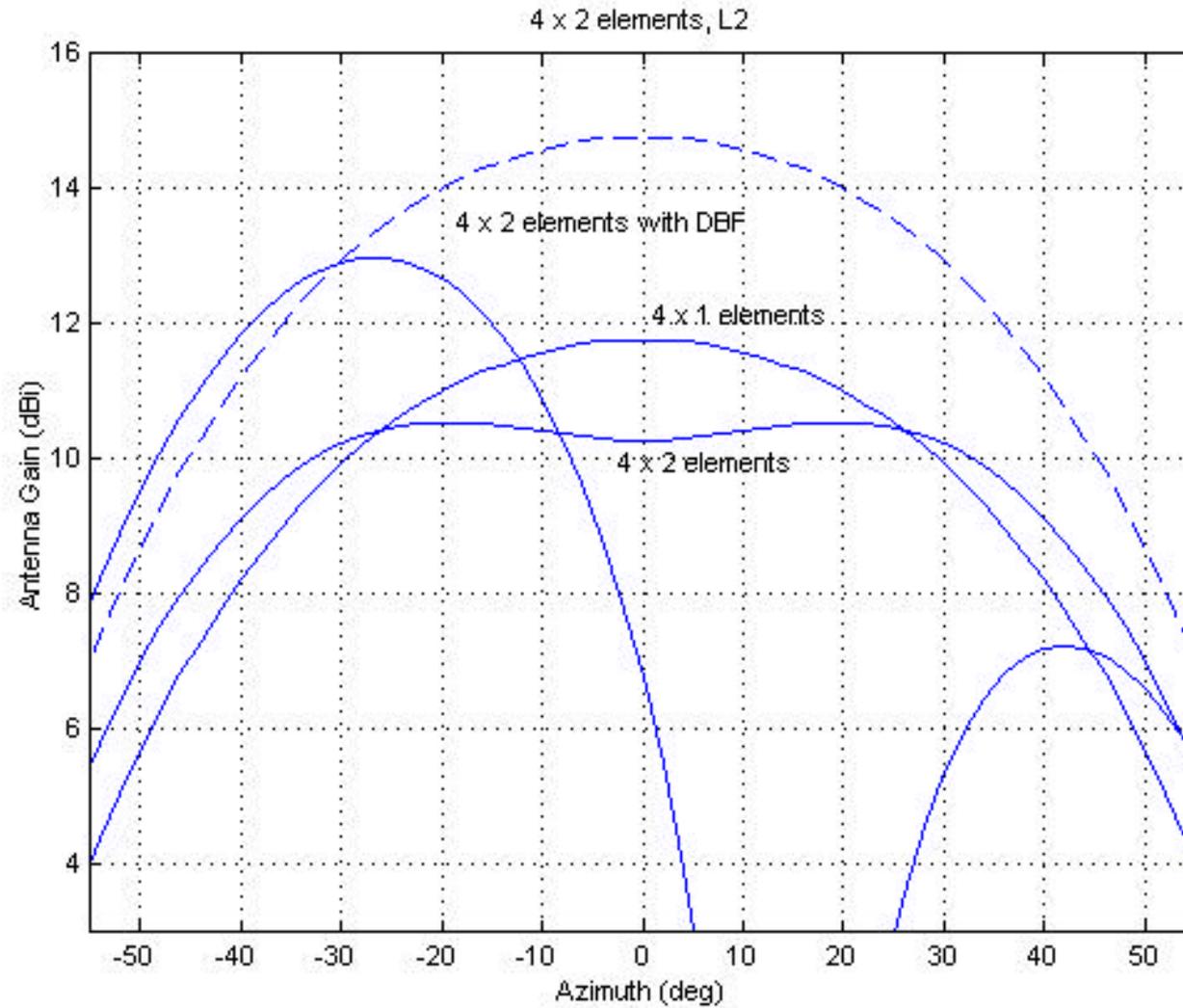
EO Future  
Programmes



- Recent preparatory work driven by ACE requirements and evolution of navigation systems
  - observation of 'modernised' GPS signals
  - observation of Galileo signals
  - performance enhancements (e.g. use of antenna beam-forming techniques; better digital signal processing)
  - further miniaturisation of electronics (e.g., integration of radio-frequency front-end)
- Adaptations to account for ACE+ needs to be addressed in system studies and in dedicated activities from Q4-02
- AGGA-3 development about to start:
  - higher integration (# channels, processor, frequency down-conversion,..)
  - performance adaptations specific to RO (e.g., optimisation of 'raw sampling', digital beamforming, wordlength)
  - new GPS and Galileo signals

*Occultation antenna split into multiple elements*





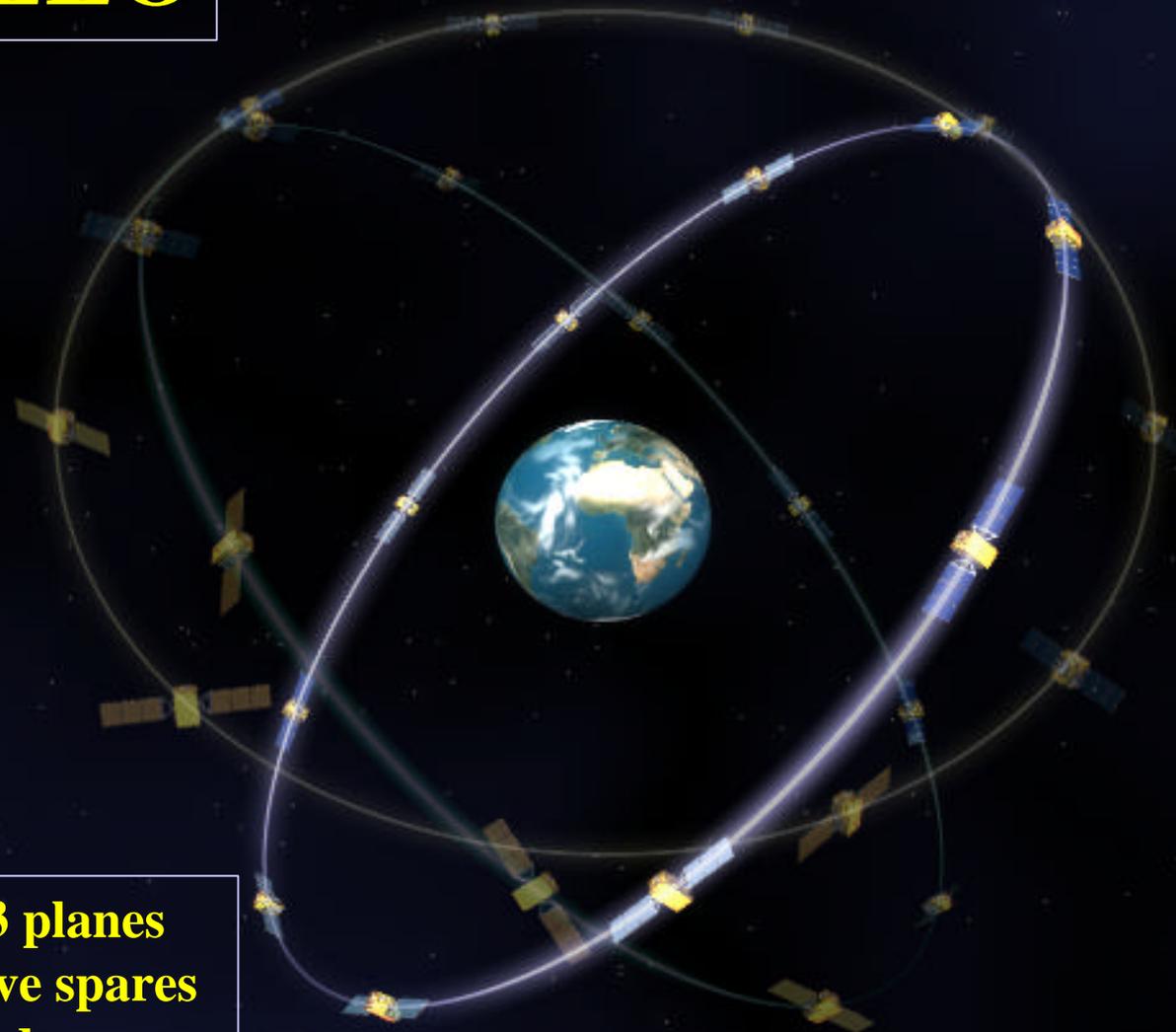
1. Transmitted power at both L1 and L2 to double in forthcoming 'replacement' satellites
2. New civil (i.e. not encrypted) modulation code L2C on all GPS by 2011 (deployment from 2003) => no need for performance-degrading 'codeless' tracking
3. Third high-performance (safety-of-life applications) civil signal at L5 (at ~1.2 GHz like L2) on all GPS by 2015 with 4 times the power of current L1
4. Pilot signal (i.e. non-modulated channel) on both L2C and L5, improving signal tracking

➡ profiling down to top of PBL

GRAS-2 to use different signal combinations according to degree of deployment of new satellites.

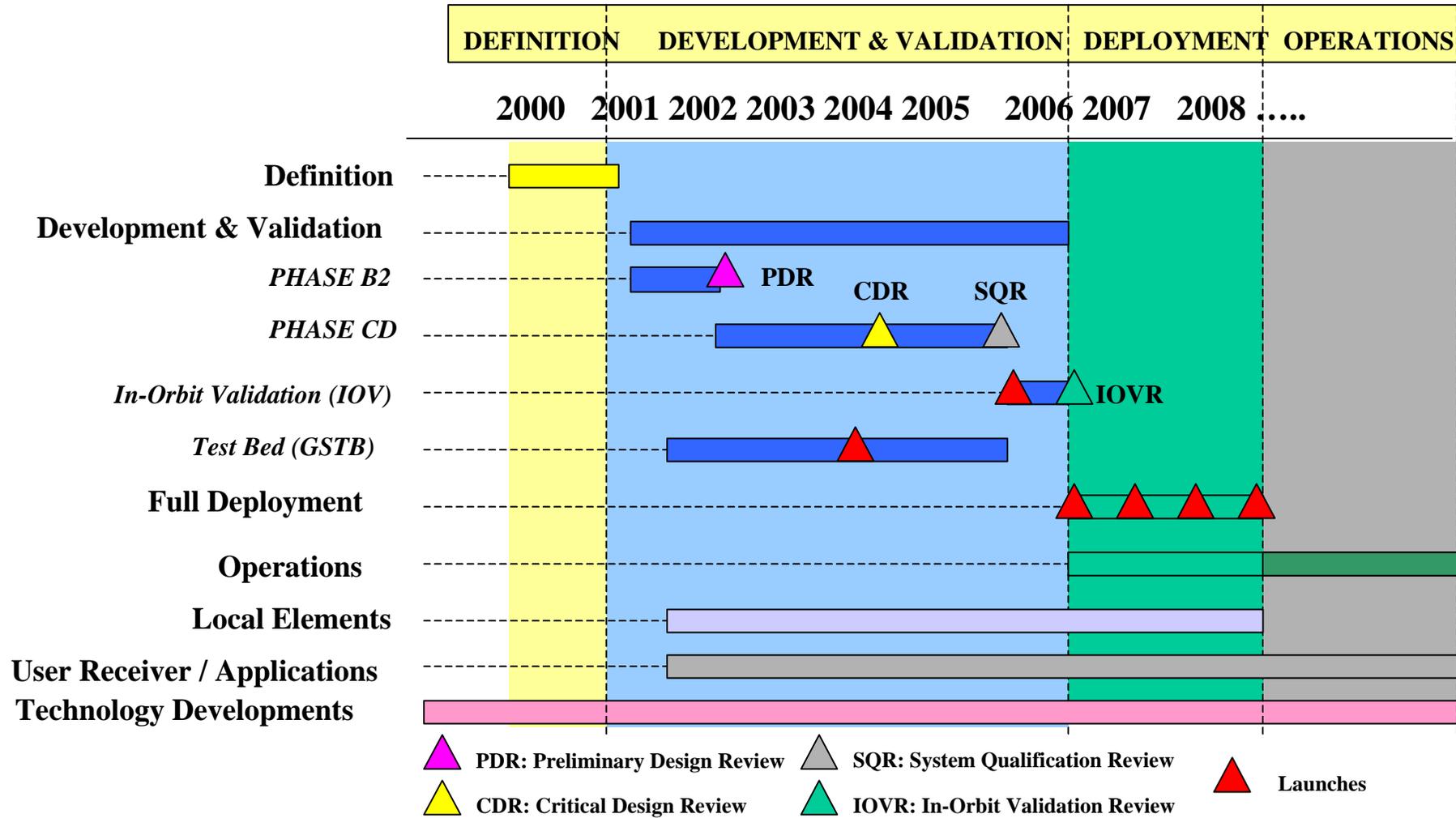


# GALILEO



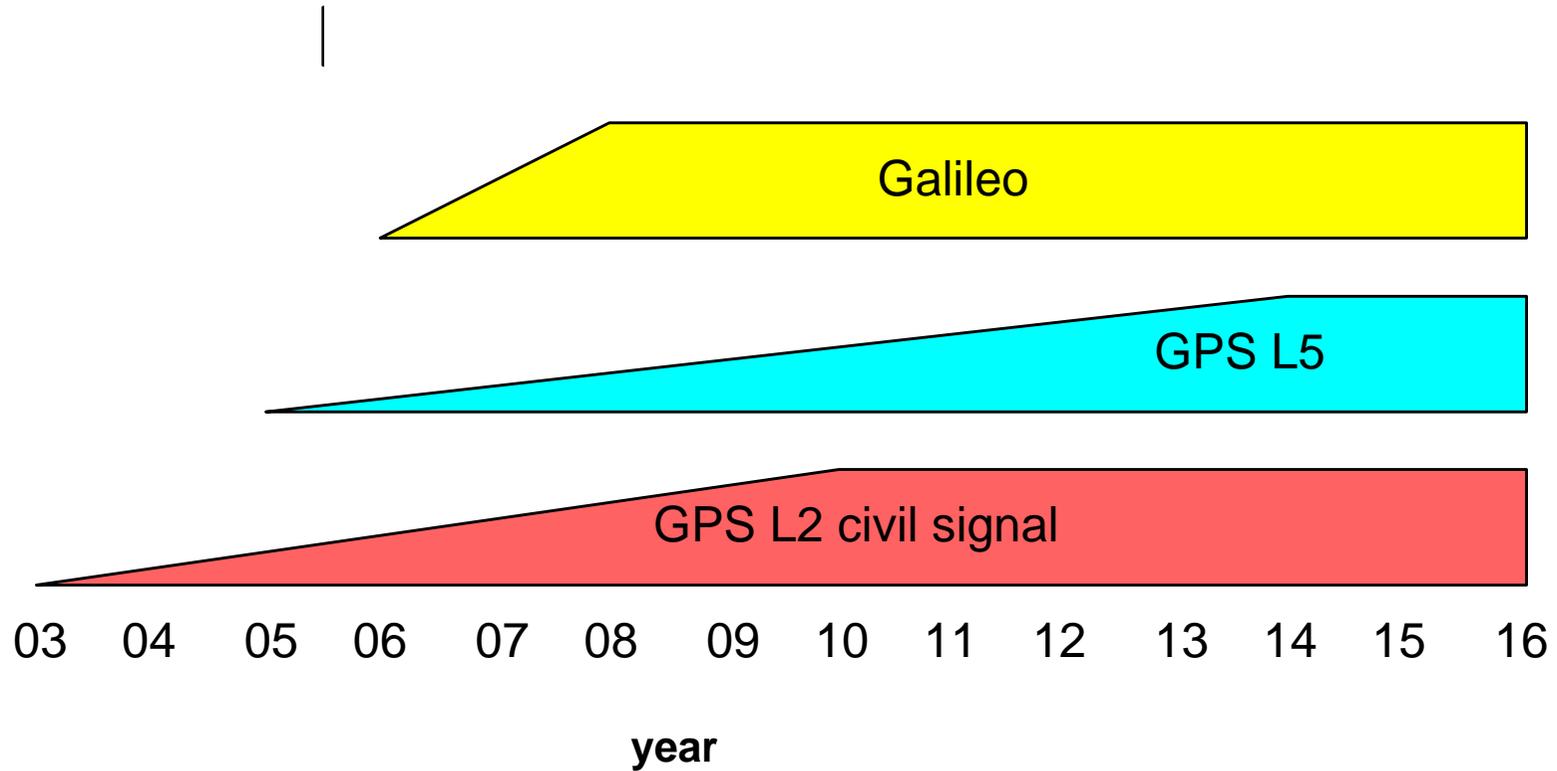
**27 satellites on 3 planes**  
**+ 3 in-orbit active spares**  
**23616 Km altitude**  
**1 + 2/3 rev/day**  
**56 degrees inclination**

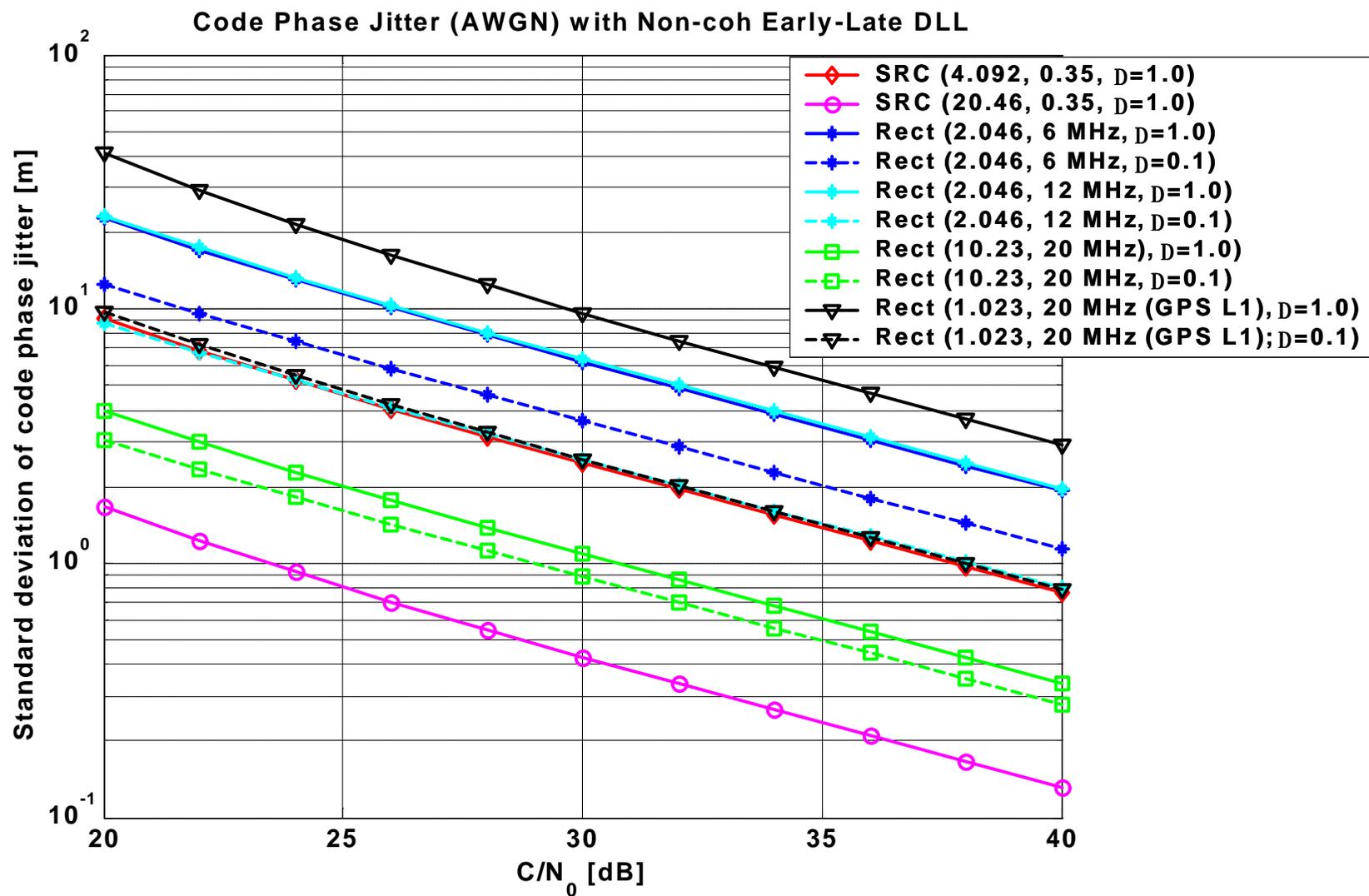
- European contribution to a worldwide inter-operable GNSS
- Planned to be operational in ~2008
- GALILEO to provide:
  - Open navigation signals
  - Integrity data
  - Commercial value-added data
  - Search-and-rescue signals
  - Navigation-related communications
- Number of transmitters more than doubled w.r.t. current scenario: >1200 profiles/day/instrument
- Reliable observations throughout LT thanks to
  - high signal power (~8 dB above current GPS L1)
  - pilot signals
  - opportunity to use precise code tracking in lower troposphere, enabled by Galileo's high rate (~15 MHz) modulation and optimised codes



- Five L-band signals (1 overlay) including:
  - 3 open signals providing navigation, integrity and commercial data in support of open (civil), safety-of-life and commercial services
  - 2 regulated signals with encryption for 'public regulated' services
- Spectrum sharing with GPS and / or GLONASS
- Large bandwidths at E5, E6

Freq. Designator	Central Frequency (MHz)	Service	Available bandwidth (MHz)
E5	1202.025	OS/CS/SS	24.0
E6	1278.750	CS/GS	40.0
E2	1561.098	GS	4.0
E1	1589.742	OS/CS/SS	4.0





- Iterations between processing and retrieval aspects, observation requirements and design:
  - first results in WATS studies (RS paper by Eriksson et al.)
  - processing/retrieval study, including end-to-end simulations (EGOPS-5) and detailed error analyses
- Technical challenges:
  - stability of equipment during an event (e.g., 1/f noise effects in receiver front-end?) → breadboards of receiver front-end will be developed in 2003
  - verification/validation issues
  - antenna design and testing
  - calibration
  - overall system design

- RO with navigation signals rapidly progressing from research stage to operational stage
- Role of GRAS mission in EPS
- New GPS and Galileo will enhance mission return (coverage, performance)
- ACE+ expected to provide improved climatology of water vapour
- Role of ESA:
  - develop, launch (and operate) space systems
  - foster innovation
  - help create and reinforce European competence and cooperation in science, applications and space technology